GIR092

General Information Report

Energy efficiency in lighting – an overview

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Making business sense of climate change

Foreword

This publication provides an overview of energy efficiency in lighting considering all the elements and how they inter-relate with one another. It is aimed at people who are concerned with improving lighting energy efficiency without inhibiting the quality of the lit environment. This includes architects, lighting designers and installers as well as building developers, facility managers and building users.

The range of topics addressed requires, at times, a greater technical depth than may be appropriate for some of the readers. However it is hoped that where this is the case the reader will be helped by the section towards the end which provides an explanation of some of the terms.

Written for Action Energy by David Loe in conjunction with the Society of Light and Lighting, Energy in Lighting panel which is a part of the Chartered Institution of Building Services Engineers who have approved the document for inclusion with the SLL Code for Lighting.

Society of Light and Lighting, Energy in Lighting panel membership:
A I Slater (chairman), E Glenny, J Gosney, D L Loe, I Maclean, V Neal, M J Perry, P Raynham, R Venning.

Society of Light and Lighting

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Introduction

In the UK, lighting consumes around 58,000GWh each year which amounts to about 20% of all the electricity generated. If we are to ensure a high quality of life for future generations this level must be reduced. The reason for this is that most of our electricity is generated by burning fossil fuels which causes carbon dioxide emissions that, in turn, contribute to climate change which could have devastating effects on the quality of life for the future.

The way a building is lit – whether by daylight, electric light or as is more usual by a combination of the two (at least for some part of the day) – will affect the performance of its occupants. This means that the human requirement aspect of lighting is of key importance. But as electric lighting is a major consumer of electricity the energy efficiency of an installation must also be a prime consideration.

Designing anything requires the designer to balance a number of inter-related elements and lighting is no exception. The elements that need to be considered for lighting have been described in Good Practice Guide 272: 'Lighting for People, Energy Efficiency and Architecture' (1). This General Information Report addresses the energy efficiency aspects of lighting and lighting installations.

The report considers all the elements and describes how they inter-relate with one another. It aims to answer fundamental questions about lighting energy efficiency for the user, the building owner or manager and the designer. It also addresses the question of Building Regulations and tax incentives aimed at controlling or encouraging reduced energy use in lighting.

Although energy efficiency is vital at a national and international level it will also have benefits for the individual end user through improved running costs. Reduced energy use means reduced operating costs and hence an improved economic performance. This results in a saving that goes on throughout the life of the installation as long as it is properly maintained.

It is important to appreciate that there are a number of elements of a lighting installation that will affect its energy consumption and, therefore, its energy efficiency performance. But in the end it is the number of units of electricity that are consumed, with respect to time, for a given level of lighting performance that will determine its energy performance.

The amount of energy used is determined by the lighting equipment e.g. the lamps and the light fittings (or luminaires as they are usually called by the industry). It will also be determined by the lighting requirement for the particular application, which includes both the task illumination and the lighting which illuminates the building. This will determine the type and number of luminaires used.

The total number of units of electricity consumed by the lighting installation will also be affected by the length of time the lighting is switched on, which will be affected by the amount of daylight that is present and whether the room is occupied, but also whether there are suitable controls, either manual or automatic, to ensure optimum lighting conditions without lights being left on unnecessarily.

Lighting equipment

For the best possible results, all the design elements need to be considered for the particular application, with a view to providing the best and most economical solution both in human and economic terms.

Towards the end of the publication, on page 28, a section entitled 'Explanation of Terms' is provided to explain those things that might be unfamiliar to some readers.

High quality energy efficient lighting makes good sense but it is necessary to consider all the elements of the equation to achieve it.

Lamp and lamp ballasts

Let us start by considering lamps, which are the basic element of any electric lighting installation.

There are two main types of electric lamp – those that emit light by heating a tungsten filament until it glows (incandescent lamps) and those that operate through an electric gas discharge (fluorescent lamps as well as those described as low and high pressure discharge lamps). In the case of linear and compact fluorescent lamps the light is generated mostly by ultraviolet radiation from the gas discharge interacting with a phosphor coating. All discharge lamps require an ancillary circuit called a ballast for the lamp to start and operate correctly.

Although there are only two main types there is a wide range of different lamps available which have different performances and hence different applications. It is important to employ the best lamp for the particular use e.g. retail outlet, office or factory. The considerations include the amount of light the lamp emits in lumens as well as its power consumption in Watts. Other performance considerations include the lamp's colour characteristics, which includes its colour appearance (i.e. whether the light appears warm or cool) and its colour rendering accuracy. Other factors also include the lamp's expected life and operating characteristics such as whether the lamp takes some time to reach full light output or takes time to switch on when it is hot.

For further details of the possibilities see the Action Energy publication Good Practice Guide 300: 'The Installer's Guide to Lighting Design' [2] or the Lighting Industry Federation 'Lamp Guide' [3] and the Society of Light and Lighting publication 'Code for Lighting' [4].

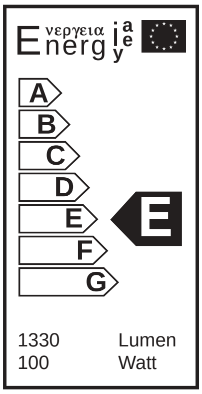
Since this report is concerned with energy efficiency it will only address those aspects of a lamp's performance that directly affects this, the main element of which is its efficacy. Efficacy is the term used to describe the amount of light emitted in lumens when the lamp has reached full light output with respect to the amount of electricity consumed in Watts.

The unit of efficacy is lumens per Watt and the higher the value the better the lamp's energy efficiency performance. Note: the term efficacy is used, rather than efficiency, because we are comparing two different units. The unit of light – the lumen and the unit of electrical power – the Watt. Hence lumen/Watt.

CE Marking and Energy Labelling for Lamps

CE Marking on lamp packaging indicates that the product meets the requirements of:

1. Low Voltage Directive for Electrical Safety (73/23/EEC as amended by 93/68/EEC).
2. EMC Directive for electromagnetic compatibility (89/336/EEC as amended by 92/31/EEC).
3. For household lamps – Energy Labelling directive (98/11/EU).



Energy Efficiency Classification	Typical Lamp Types
A or B	Fluorescent tubes and CFLs
C or D	Tungsten Halogen
E	GLS (25W – 200W)
E or F	Candle Lamps
G	Striplights

***Figure 1** CE Marking and Energy labelling for Lamps*

As examples of selecting the most energy efficient lamp, it means where possible, use fluorescent lamps where, in the past incandescent lamps were used. Or where linear fluorescent lamps are to be employed, to use the more efficient T8 or T5 lamps which have 26mm and 16mm tube diameters respectively.

These lamps have a higher efficacy than the old T12 lamps, which are 38mm in diameter. But these are only examples and the whole gamut of lamp performance needs to be considered.

Incandescent filament lamps and fluorescent lamps are labelled according to their energy efficiency classification in accordance with European energy labelling directives. The classification system ranges from A to G with A being the most efficient (3).

Although the process of light production will affect a lamp's efficacy so will any ancillary circuit. This includes the ballast unit used by discharge lamps to start the discharge and to control its operation. Also most discharge lamps require circuits to ensure a high power factor, which helps to minimise other losses in the building wiring.

The operation of a discharge lamp, and the energy consumed by the ballast circuit, will be determined by the type of ballast used. In the past, ballasts were relatively simple wire-wound devices and consumed an appreciable amount of energy – typically 10-20% of the lamp wattage. Modern ballasts however, often use electronic circuits.

These can have a number of benefits. In the case of fluorescent lamps they can operate the lamp at high frequency typically 30kHz rather than at the mains frequency of 50Hz. This has the effect of running the lamp more efficiently, but it also reduces the degree of perceptible flicker, which for some people makes it more comfortable.

They can also reduce the lamp light output through step switching or dimming. Modern ballasts usually consume less energy than earlier types, which means that the overall efficiency of the lamp circuit is improved, but this must be checked. For fluorescent lamp ballasts this is defined by a CELMA energy class, which should be marked on the ballast casing (5). Current EU regulations demand that all ballasts should be either a type A, B or C class unit, where A is the most efficient and C the least. Class C, however, will be phased out from 21st November 2005 (5).

The development of low and high pressure discharge lamp ballasts has not moved as quickly as those for fluorescent lamps but low loss and light output controllable ballasts are already beginning to appear.

Table 1 shows the typical efficacy range for most lamp types. For all lamps a range of values is shown. This is because efficacy is not a constant for a particular lamp type but depends also on its power rating (Watts) and hence its light output (lumens) but also its construction.

Although Table 1 indicates the typical efficacy for a range of lamps, for more accurate data the lamp manufacturers should be consulted. Lamp manufacturers' catalogues will also provide details of all aspects of lamp performance.

In recent times a new lamp technology has begun to emerge. This is the light emitting diode or LED. This is a device that incorporates a high purity semiconductor that when activated electrically generates light. Currently the devices are being used mainly for signalling and decorative purposes but eventually they are likely to develop to a point when they will become appropriate for more everyday applications and will need to be considered as another possible light source.

Lamp Type	Efficacy lumen/Watt
Incandescent – Tungsten Filament	8 – 12
Incandescent – Tungsten Halogen	12 – 24
Compact Fluorescent	50 – 85
Tubular Fluorescent	65 – 100
Low Pressure Sodium	100 – 190
High Pressure Sodium	65 – 140
High Pressure Metal Halide	70 – 100

Table 1 *Typical lamp efficacies*

Select the lamp for the application particularly with regard to its colour performance and its operating characteristics etc. Then select the lamp with the highest efficacy (lumen/Watt). Use the most energy efficient ballast units, and for fluorescent lamps use those with a CELMA energy rating of A or B and with the required control e.g. dimming etc.

Luminaires (light fittings)

Although using a high efficacy lamp is crucial for an efficient lighting installation the efficiency of the luminaire is also important. For example, if a luminaire only emitted half of the lamp light output this would in most cases be seen as wasteful.

The luminaire, or light fitting as it is often referred to, is the equipment that physically supports the lamp and provides its safe connection to the electricity supply. It also provides protection for the lamp, particularly in hazardous areas and areas where broken glass would be a particular problem e.g. food processing etc. It also provides the optical control that ensures the light is directed to where it is required as well as obstructing it from those areas where it is not needed. This involves the use of reflectors, refractors and/or diffusers. The luminaire also has an appearance or style that will be another consideration for the designer.

Inevitably the optical elements of the luminaire will absorb light. This means that not all the light from a lamp will emerge from the luminaire as some will be used in the process of redirection to create the light output pattern required. The problem is how best to define the optical efficiency of a luminaire?

The simplest way of describing the optical efficiency of a luminaire is by its Light Output Ratio (LOR). This compares the total light output of the luminaire with respect to the total light output of the lamp(s) and is expressed as a fraction or percentage. However, this takes no account of where the light is going. Hence a luminaire that projects all its light down could have the same LOR as a luminaire that projects all its light up. But they would have very different efficiency ratings in providing a level of light on a horizontal working surface of a desk or bench (see figure 2).

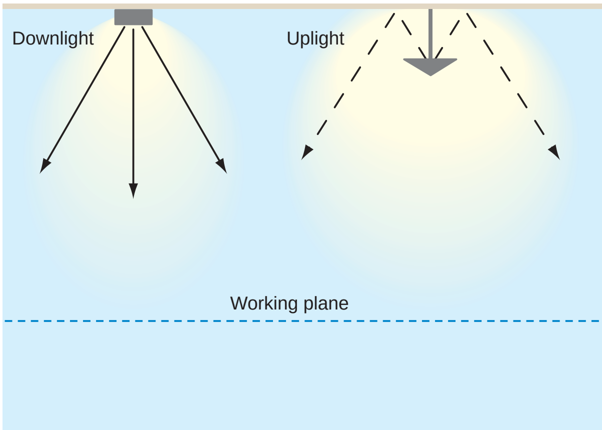


Figure 2 *Schematic performance of downlight and uplight luminaires to provide a working plane illuminance*

However, to compare the relative efficiency of two luminaires with similar light output distribution shapes then comparing the Light Output Ratios will be fine. Some luminaires have both downward light and upward light. Usually the down-light is used to provide task illumination while the up-light provides some light on the ceiling which will usually have a beneficial affect on the appearance of the room – it helps to make it appear 'light' which is important to the satisfaction of people. In this case the LOR can be divided into an upward component and a downward component. These are described as the Upward Light Output Ratio (ULOR) and the Downward Light Output Ratio (DLOR). The sum of the two gives the Total Light Output Ratio (see figure 3). Again, these can be used to compare the efficiency of luminaires with similar light output distribution shapes.

The critical consideration is to assess when two luminaires have sufficiently similar light output intensity distribution shapes, sometimes described by their polar curve (see figure 3). Unfortunately there is no precise answer to this but usually if the light output distribution shape appears similar then Light Output Ratio (total LOR, DLOR and ULOR) comparisons will often be adequate.

Because many lighting installations comprise a regular array of identical luminaires fitted on, or recessed into a ceiling, the industry has devised a way of estimating the number of luminaires that are required to provide a particular illuminance (or lighting level measured in lumens/square metre or lux). Usually this is for a horizontal plane, like a desk top, anywhere in a room. To achieve this it is necessary to know the proportion of the lamp light output that will arrive on the horizontal plane. This depends not only on the luminaire performance but the room size and its proportions, as well as the reflectance of the room surfaces. This installation performance characteristic is known as the Utilisation Factor (UF). In this case two luminaires can be compared, in terms of efficiency, by comparing their Utilisation Factors for the same room conditions.

The luminaire with the higher UF will be the most efficient. However, the appearance of the lighting in the room may not be the same unless the luminaires have similar light output distribution shapes as well. In some cases where all the light is directed downwards, using optics that allow no light on to the walls the room could appear gloomy and be generally unacceptable to the users.

Most luminaire manufacturers provide LOR information for many of their luminaires unless they are mainly for decorative purposes. They also provide UF information for luminaires that they expect to be used in a regular array for a range of conditions of room size and for a range of room reflectance values.

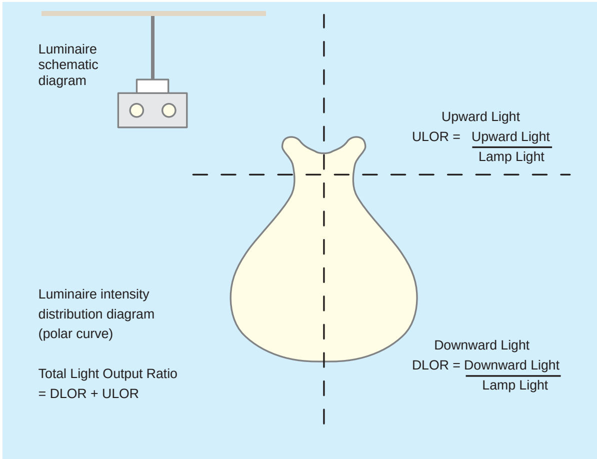


Figure 3 Typical light output distribution (polar curve) of a diffuser type luminaire equipped with fluorescent lamps showing Upward and Downward Light output components.

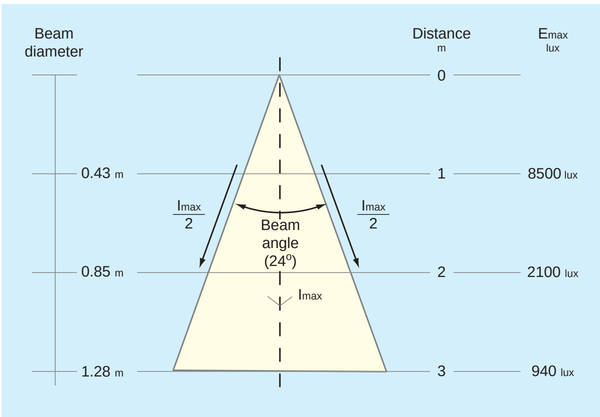


Figure 4 Typical method of showing the performance

However these pieces of information are not usually contained within the standard catalogue but in a publication which shows the photometric data. Nowadays this is usually provided electronically from a CD or on the Internet.

So far we have considered luminaires that are used mainly to provide what might be called general illumination rather than luminaires that produce a beam of light. The latter includes desk lights or display lighting luminaires. In this case luminaires can only be compared by the illumination they provide in terms of the illuminance at a particular distance and the beam angle (see figure 4). This information can also be obtained from luminaire manufacturers.

Select the luminaire for the particular lighting requirement, and hence its light output distribution shape, and assess its efficiency in terms of either:

1. **Light Output Ratio using either total LOR or Downward LOR and Upward LOR as appropriate**
2. **For luminaires to be used to provide a general illumination from a regular ceiling array use Utilisation Factor (UF)**
3. **For spotlights and similar, use illumination performance data.**

Lighting controls

The third item of equipment in terms of energy efficient lighting is controls. But this time we are not concerned about the energy efficiency of the item itself but what it can do in terms of creating an energy efficient lighting installation by ensuring that lights are only used when they are needed.

In the 'Introduction' to this report energy efficient lighting was described as a combination of efficient equipment and an efficient lighting installation, and controls are part of the latter. But it will be useful to consider them here to describe the possibilities.

Basically there are two types of lighting controllers – switches and dimmers. These can be activated manually or automatically by time switches, occupancy (or presence/absence) detectors and light sensors. The different control elements can be used on their own or in combination, depending on the requirements.

Manual local switches and dimmers are either fixed to the fabric of the building or can be activated remotely by hand held controllers that use infrared, microwave or ultrasonic signals. Manual controls can also be activated via a telephone or personal computer. For manual controls to be effective they must be easy and logical to use otherwise they will be ignored by users. However, even when manual controls are well designed, people are notoriously bad at switching lights off when they are not needed.

Time-activated switches can be used to switch lights off at set times of the day such as lunchtime or any other time when people will be out of the work area. However, a manual override must be provided to allow the time switch to be over-ridden when required either to switch lights on or, if appropriate, to switch lights off. Time switches can also be used to switch lights on at a set time each day.

Occupancy or presence detectors can be used to switch lights on as people enter a room and off again when they leave, although a time delay must be included to ensure that people are not plunged into darkness by the lights switching off before they have left the room. They can be used in conjunction with task lighting where the user switches the lighting on when required but relies on an occupancy detector to switch the lights off when they have left the area. Occupancy detectors can also be used by security and cleaning staff at night when only a reduced amount of light is necessary. These can be switched on and off automatically as the staff move around the building. Unfortunately, this can also act as a signal to an intruder that the security staff are near by.

The third element of automatic controls is the light sensor controller. This device can be used to switch lights off when there is adequate daylight and on again if there is not. However, it is probably best if the switch-on is activated manually, using the light sensor to switch them off. Light sensors can be very effective when used in conjunction with dimmers to top up daylight to a fixed illuminance level as required. This type of control can also be used to compensate for the fall off of lamp light output throughout the life of the lamp – usually this only applies to fluorescent lamps.

Some manufacturers produce luminaries that incorporate their own control sensors. These are sometimes described as 'intelligent' luminaries and can incorporate switches or dimmers. However, the designer will need to specify the particular required operation.

An important consideration of any automatic lighting control system is that it must be user friendly. People will very soon become annoyed if they feel that they are being dictated to by the control system and will often try to sabotage the process. The control system must be logical to the occupants and its action should be hardly noticeable. The supplier will also need to provide an operation manual to ensure ongoing satisfaction.

For further information about lighting controls see Good Practice Guide 160: 'Electric Lighting Controls'(6).

Good lighting controls, including switches and dimmers, operated either manually or automatically via light and occupancy sensors, can provide important benefits in terms of energy efficiency but they must be user friendly – in other words they must be seen by the occupants as an important benefit and should hardly be noticeable in their operation.

Lighting design and operation

Lighting installation design

So far this report has considered the various equipment issues that need to be considered to provide an energy efficient lighting installation, but the design of the installation where all the parts come together to form an installation for the application of the building and its users is just as important. In fact, in terms of the overall productivity it will be even more important because however efficient an installation is in conserving energy if it is not appropriate for the particular activity it could be counter productive.

Early in the lighting design process it will be necessary to assess the occupants' tasks so that the lighting requirements can be determined. This will enable such things as 'how much' and 'what type of light' are required for the application. It will also address where any supplementary lighting is required for safe circulation and to create a building that has a pleasant appearance. The lit appearance of a building is an important aspect of lighting design and where this has been ignored, and for example, a gloomy appearance building has resulted, user dissatisfaction has sometimes occurred.

Obviously, the amount of task light provided will have an effect on the amount of energy consumed. If an area is lit to a level of say 300lux it will generally consume half the energy of an installation that provides 600lux. The task illuminance recommendation is an important guide to ensure user productivity and any reduction can be a false economy.

Illuminance is the technical term to describe the light level on a particular surface, usually the working surface (e.g. a desktop), but it could also be the floor for circulation spaces like corridors. The units are lumens per square metre or lux (1lumen/m^2 = 1lux).

The actual amount of light provided depends on the difficulty of the task and on the quality of the vision of the occupants. For example, a level for an office could be 300lux while the level for a factory involved in high precision work might be 1500lux. Also if the occupants are advanced in years then a higher level of illuminance may be necessary. The Society of Light and Lighting, which is a part of the Chartered Institution of Building Services Engineers, provides recommendations for task illuminance for a range of different situations in their Code for Lighting (4).

Many lighting installations comprise a regular array of identical luminaires, distributed evenly across the ceiling to provide a uniform illuminance on the working plane. This allows tasks to be carried out almost anywhere in the room. To achieve this, the luminaires must not be spaced too far apart for the light output distribution of the proposed luminaire otherwise there are likely to be places where the illuminance is too low. If this type of uniform lighting is the aim of the designer then the installation will need to meet an illuminance uniformity recommendation of 0.7 (illuminance uniformity = minimum illuminance/ average illuminance). This type of lighting is the bedrock of lighting design and if a luminaire is selected that provides sufficient light on the walls and ceiling it can be used to provide both the task lighting as well as the building appearance lighting.

The Society of Light and Lighting has produced a table showing the lighting energy targets for a range of situations using particular lamp types (4). The targets are in terms of the average power density (Watts/m^2) which is likely to be required using good quality equipment in a well maintained environment. Table 2 shows the power density targets together with accompanying explanations; it has been reproduced with the permission of the Society of Light and Lighting.

The following table provides targets of average power density for a range of applications with particular maintained task illuminances and are based on current good practice. The values, have been achieved, using efficient lamp circuits (based on T8 lamps and standard electronic HF ballasts) and luminaires in well designed installations. They are based on the following criteria:

- An average sized empty room (Room Index 2.5)
- High room surface reflectances (Ceiling 0.7; Walls 0.5; Floor 0.2)
- High degree of installation maintenance (Luminaires cleaned every year, room surfaces every three years, bulk lamp replacement every 10,000 hours).

It should be noted that the values could be higher or lower where variations in criteria are made.

Lamp type	CIE general colour rendering index (Ra)	Task illuminance (lux)	Average installed power density (W/m²)
Commercial and other similar application e.g. offices, shops and schools *			
Fluorescent – Triphosphor	80 – 90	300	7
" "	"	500	11
" "	"	750	17
Compact Fluorescent	80 – 90	300	8
" "	"	500	14
" "	"	750	21
Metal Halide	60 – 90	300	11
"	"	500	18
"	"	750	27
Industrial and manufacturing applications			
Fluorescent – Triphosphor	80 – 90	300	6
" "	"	500	10
" "	"	750	14
" "	"	1000	19
Metal Halide	60 – 90	300	7
"	"	500	12
"	"	750	17
"	"	1000	23
High Pressure Sodium	40 – 80	300	6
" "	"	500	11
" "	"	750	16
" "	"	1000	21

Table 2 *Lighting energy targets: average installed power density per application reprinted from the Code for Lighting (4)*

*Values do not include energy for display lighting

All lighting installations need to be maintained. This involves cleaning the lighting equipment, lamps and luminaires, to ensure that light is not being wasted through the obstruction by dirt. Also since most lighting installations depend on a certain amount of reflected light from the room surfaces these also need cleaning or redecorating periodically. The regularity of cleaning will depend on how dirty the environment is. The question of maintenance is an important one because the designer will need to assess what the reduction of light will be with respect to time due to dirt build-up and due to the fall off of lamp light output as the lamp ages. This enables them to ensure that the required task illuminance is provided at the end of the maintenance cycle.

If this is not assessed correctly then there could be an over provision of light and energy will be wasted. Equally if the client does not carry out the recommended maintenance programme then they will be paying for light that is not provided and the occupants will not have the required lighting conditions to ensure optimum performance. For more details see GPG272 (1) and SLL Code for Lighting (4).

So far we have only considered lighting installations where the lighting provision is uniform over the whole space. An alternative approach could be to provide a moderate background level of uniform illuminance with additional local illuminance provided for task illumination at the points required.

For example an open plan office might be provided with an overall background illuminance of 300lux but with the option of an additional 200lux at each work-station to provide a minimum working illuminance of 500lux. This approach is often described as task and building lighting or task and background lighting. But the approach has the potential for energy efficiency. For example, from Table 2, the target value of power density for 300lux, using triphosphor fluorescent lamps in an office, is $7W/m^2$ but for 500lux using the same lamp type the target is $11W/m^2$. Some of this difference will be used to top up the illuminance at the work place but probably no more than half of it making an average power density of $9W/m^2$. This represents a saving of nearly 20% but greater savings are possible.

However, in this lighting approach it will be essential to ensure that the lit appearance of the office is satisfactory i.e. that it appears suitably 'light' and 'visually stimulating'. This form of lighting, by having a higher task illuminance to the background illuminance, can also provide improved performance but it will need careful design by an experienced designer. There is also some evidence that users prefer this design approach particularly when they have at least some control of the task lighting.

The lighting design must provide conditions for the users to carry out their tasks safely, comfortably and with high productivity – this means following the recommendations provided by the Society of Light and Lighting. The lit appearance of the building interior will also be important. These requirements will sometimes be possible through the use of non-uniform lighting that can also have energy saving benefits e.g. a task and building lighting design approach.

Always use experienced and qualified lighting designers for the best results.

Daylight availability and electric lighting use

An important area of lighting energy efficiency is taking full advantage of the daylight availability and, therefore, reducing the need for electric lighting. Everyone prefers to work in daylit spaces although the exact reasons are unclear. It may be the colour performance of daylight, which is always perceived as the most accurate, or that side windows provide attractive light modelling of objects including people, or perhaps it is just the benefit of a view out. Whatever the reason windows are seen as an important human requirement and they need to be designed to meet the needs of the building and its occupants. But for optimum energy efficiency it will be necessary to provide electric lighting to complement the daylighting to the best advantage. It will also be necessary to use lamps which have a colour appearance, or Correlated Colour Temperature, of around 4000K so that the daylight and electric light will blend together reasonably well. However it will never be perfect because the colour of daylight changes.

In daylighting terms the larger the window area, or more correctly the glass area, the larger the amount of daylight that will be admitted. But the window will also have implications on the thermal performance of the building and its energy consumption. Windows not only admit daylight but also admit thermal energy, which will heat the interior. This can be useful in winter but it can cause over-heating in summer. Some of the thermal gain problems can be corrected by installing some form of window blind system, which can also be used to provide glare control. But the blinds will reduce the amount of daylight so they should only be used when necessary e.g. when the window is exposed to direct sunlight. Windows are also likely to be a source of heat loss in winter which means they need to have a high insulation value.

All of these things need to be considered at the design stage to produce an effective window design. But just how much light will a window provide and what is its potential for saving electric light energy? This is a little complicated because although a window is of fixed dimensions the amount of light it provides will not be constant throughout the year because of changing sky brightness conditions caused by time of day and year, as well as changing weather conditions. Because of this, daylight is often described in terms of the proportion of unobstructed daylight outside the building on a horizontal plane to that which will arrive inside a building at a particular point. This is called the Daylight Factor and is described by a fraction or percentage.
This can be translated into a likely minimum illuminance by knowing the proportion of a day, averaged throughout the year that a particular illuminance is likely to be exceeded.

As an example, figure 5 shows a plan of a room with windows in one side with Daylight Factor contours across a horizontal plane at desk height. Figure 6 shows graphs of the diffuse illuminance availability for London and Edinburgh relative to a percentage of the working day.

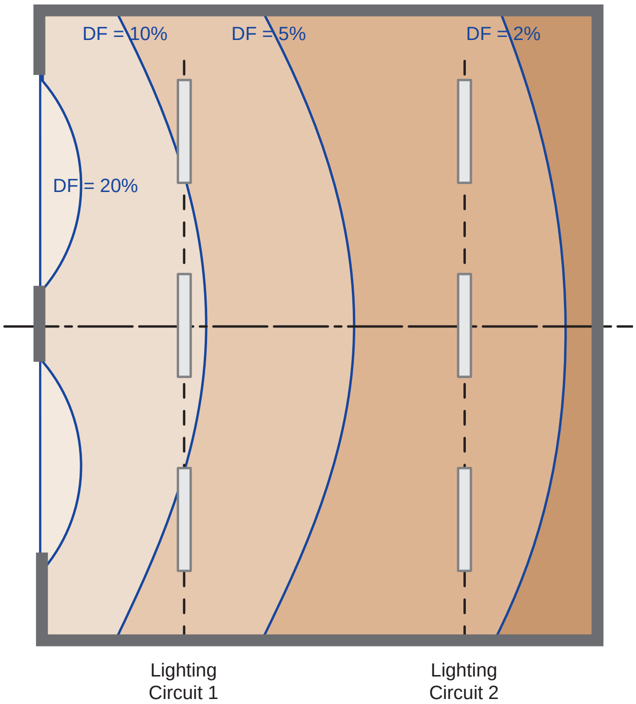


Figure 5 *Room plan showing window positions and example daylight factor (DF) contours. Also ceiling mounted luminaires and electric lighting circuits.*

From this graph it can be seen that for 60% of the year for a 09.00 – 17.00 length working day, in London, an illuminance of approximately 13kilolux will be exceeded. This will mean for the room shown in figure 5 the area between the window and the 2% contour is likely to have an illuminance of at least 260lux for 60% of the 09.00 – 17.00 day averaged throughout the year. (i.e. 13000 x 2/100 = 260lux). From this an estimate of the amount of electric light required for a particular illuminance can be found.

Daylight illuminance information can be calculated using one of a number of methods, usually using a computer, but as a simple rule of thumb useful daylight will only penetrate into the room a distance from the window of twice the window head height above the working plane level. This does not take account of all the parameters so it should be used with great caution.

Although daylight illuminance can be assessed, the important issue is to ensure that the electric lighting is not switched on when it is not required. The first thing to ensure is that the luminaires which serve the daylit area can be switched off independently of the others. This requires the luminaires to be connected in circuits that apply to zones parallel to the window wall (see figure 5). It also requires that luminaires in the daylit area can be switched off either manually, which means having switches positioned close to the occupants and the switches clearly labelled so that the correct lights are switched off, or automatically.

One form of automatic control is to use light sensors connected to the lighting circuits near the window. These will usually monitor the total illuminance on the working plane and switch the lights off when they are not required.

However to ensure that the action of switching lights off is hardly noticed it is recommended that they are switched off at a combined daylight and electric light level equal to at least three times the required illuminance.

Usually the lights are best switched on manually, but the circuits can be arranged to switch lights on when the illuminance level drops below a predetermined level if this is seen to be appropriate.

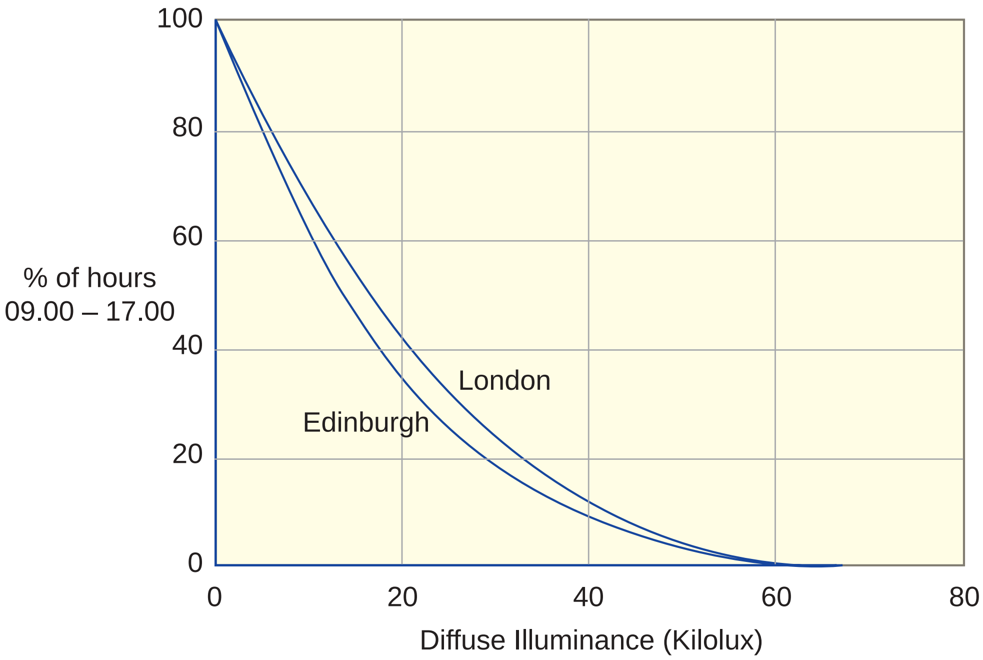


Figure 6 *Diffuse daylight illuminance availability for London and Edinburgh for a 09.00 – 17.00 hour day.*

The best form of combined daylight and electric lighting control is where the luminaires can be dimmed. This means that the lamp light output can be continually adjusted to provide a predetermined illuminance at any time of the day. This is more costly in terms of equipment but since the lighting installation is likely to be around for up to twenty years it could still be cost effective.

It has been indicated how windows can provide useful energy efficiency benefits but to assess in detail the likely performance it will be necessary to consider the physical parameters of a particular situation. This will include not only the window area but also its position in the room as well as the transmittance of the glass. It will also include the orientation of the window, as this will have an effect on the daylight illuminance value.

For example, in the UK, a south facing window will generally provide more light than the same area of window facing north. The degree of external obstruction to the window will also need to be considered because this will reduce the amount of daylight entering the building. So far we have only considered windows but rooflights are a possibility in single storey buildings and on the top floor of multi-storey buildings. These can be extremely effective in providing daylight but sun penetration needs to be considered.

Another consideration regarding windows is when they are fitted with blinds to reduce or eliminate glare. In this case people will often close the blinds when they are needed but forget to open them when they leave. This means that, possibly, the blinds are still closed next morning when they are not needed, and if this goes unnoticed then the electric lighting could be switched on unnecessarily to compensate. A solution to this is to have automatically controlled blinds which open fully in the morning before the occupants arrive.

This form of control can also set the angle of louvre blinds to exclude sunlight automatically but still allow some daylight to enter. A simpler solution to this is for night-time cleaners to open the blinds fully before the occupants arrive.

It is not the purpose of this document to cover the details of window design, which is a specialist subject. For further information see Good Practice Guide 245: 'Desktop Guide to Daylighting' (7), CIBSE Lighting Guide LG10: 'Daylighting and Window Design' (8) and BRE publication 'Designing Buildings for Daylight' (9).

The provision of daylight in a building can have important benefits on the productivity of the occupants. It can also have important benefits in saving energy used for lighting. But this will require the careful design, or assessment of the window system, as well as the electric lighting so that it can complement the daylight when required. For this careful design of the lighting controls will also be necessary to achieve a system that is both energy efficient and user friendly.

If necessary seek expert advice.

Occupancy and electric lighting use

In the previous section this report considered switching lights off, or dimming them down, when the area they serve receives some amount of daylight. We now consider switching lights off when a room or work-station is not occupied. This is usually described as occupancy or presence/ absence control and is achieved by having sensors which detect people either through their movement or through the heat from their bodies.

These controls can be used to switch lights on as a person enters a room and off again after they have left. This avoids lights being left on unnecessarily. They can be used to operate task lighting at an individual work-station, or lighting in rooms which are used infrequently, such as cloakrooms or storerooms. Although we are primarily concerned with energy efficiency, occupancy controls can also be used to switch lights on where people enter the room with their hands full. This can provide user safety.

The control circuits will need to include a time delay to allow people to leave the space safely and to avoid lights being constantly switched on and off. Frequent switching of fluorescent lamps can shorten their life unless appropriate control gear is used. Lamp manufacturers quote the life of a fluorescent lamp on the basis of eight switch-on operations per 24 hours and averaged over the life of the lamp (3).

A question often raised by users is, should they switch fluorescent lamps off when they leave a room if they expect to return to the room later, or leave them on? There is a myth that has circulated that a fluorescent lamp uses high energy at switch-on and therefore it is best to leave them on. The answer, in terms of energy use, is always switch them off as the energy used at switch-on is tiny compared to the operating energy consumption.

Occupancy detectors can be wall, or ceiling mounted but the sensor must be able to detect an occupant at all times. This may require more than one sensor to cover an area. Sensors must be sufficiently sensitive to operate when required but not too sensitive that they respond to extraneous signals e.g. a blind moving in the breeze.

An option is to combine an occupancy operated switch with a manual switch. The occupant switches the lights on manually when required and the occupancy detector switches them off when they have left.

One of the complications of this form of control is where there are a number of people working in a space with different occupancy patterns e.g. an open plan office. In this case the lighting installation will need to be designed so that the occupancy controls only operate the lighting associated with a particular person. This may mean a lighting installation that combines individual task lighting with a system of building, or background lighting (1). This arrangement requires building lighting which will need to be switched on whenever the daylighting is not sufficient and any one person is present. This will allow people to move about easily and to give the space a sense of visual pleasantness. As other people arrive they will switch on their task lighting as they require it, which will be switched off again, after a suitable delay, by their work-station occupancy control when they leave. When the last person leaves the space the building lighting will also be switched off. Building lighting can also be connected to the daylight sensor.

It is difficult to say just how effective this form of control is in saving energy without considering an actual situation. But there is no doubt that people are good at switching lights on as they need them but are inclined to leave them on when they leave, particularly with a space that is multi-occupancy or a shared space like a corridor. This suggests that some form of automatic controls that switches lights off when the room, or part of the room is daylit and that switches lights off when it is not occupied will provide worthwhile energy savings particularly over the life of the installation.

Use occupancy controls to ensure that lights are not left on unnecessarily. This will make for an energy efficient lighting installation and save the user money. But make sure the controls are user friendly.

Regulations and incentives

The UK government has introduced regulations designed to improve the overall energy efficiency of lighting installations and a brief summary is provided but the reader is encouraged to study this in detail – see further reading (10, 11 &12). It has also introduced tax incentives to further encourage energy efficiency through a system called Enhanced Capital Allowance (ECA) (13). This allows a tax reduction when energy efficient equipment is purchased.

Building Regulations

To ensure energy efficiency in lighting the Building Regulations 2000, (as amended in October 2001), Parts L1 and L2, for England and Wales have minimum standards of lighting energy efficiency. Part 1 covers dwellings while Part 2 covers most other building types.

In new dwellings, to comply with the Regulations, it is necessary to install permanently a reasonable number of either basic lighting sockets or complete luminaires that will only accept low energy lamps with an efficacy of not less than 40lumens/Watt. This includes most compact and tubular fluorescent lamps. As a rough guide at least one in three lighting points should use low energy lamps which should generally be those lights that are used most frequently.

Also for new dwellings the Regulations include a requirement for the exterior lighting. These direct that all exterior lighting attached to the building, including entrance porches, but excluding garages and car ports, should only accept low energy lamps with an efficacy of not less than 40lumens/Watt. Or as an alternative, should include lighting controls that will automatically extinguish lights when not required or when there is sufficient daylight.

The requirements for other building types, either new or where significant refurbishment has been carried out, is more complicated. But the overall requirement is to use a reasonably efficient lamp, control gear and luminaire, and to provide control systems that enable effective use of daylight where appropriate. There are a number of ways of complying with this by using specified lamps of high efficacy or by using lighting equipment such that when the average lamp and luminaire efficiency is calculated for the whole building the lighting design efficiency is not less than 40lumens/Watt. This is a complicated calculation and will normally be carried out by the lighting designer. Other approaches are included as well as requirements for display lighting.

There are also requirements concerned with lighting controls. In general these aim to encourage the maximum use of daylight and to avoid unnecessary use of lighting when spaces are unoccupied.

The information given here is only a brief summary of the Regulations and for more details see Installer's Lighting Guide 004: Lighting requirements for Part L of the Building Regulations England and Wales (11).

The regulations for Scotland are similar in intent but the requirements are different. They are described in Installer's Lighting Guide 005: Lighting requirements for meeting the Technical Standards for compliance with the Building Standards (Scotland) Regulations 1990 – sixth amendment (12).

Incentives – Enhanced Capital Allowance (ECA)

The UK government is keen to encourage users and installers wherever possible to use energy efficient equipment. To this end it has introduced a scheme to allow tax relief to businesses on some items of equipment that will help to reduce the energy used for lighting. These include some lamps, luminaires or light fittings and controls (13).

Conclusion

The preceding material has traced the ways in which energy used for lighting can be minimised through the equipment used, the lighting installation design and by the lighting use with respect to time. The best installations will be those which use all the elements that are appropriate for the application in a way that does not alienate the occupants. It must be stressed that although energy efficiency is important so is the requirements of the users for the applications of the building. This means that the installation and its controls must be logical and user friendly because without it the occupants will rail against it and possibly sabotage the system.

This approach is leading to the consideration of the total annual amount of electric energy used for lighting. This approach will give the designer and user more flexibility in their approach to suit the particular requirements for the application and the building. This approach will require energy efficiency in lighting to be specified in terms of kWh/year or kWh/m^2/year, instead of power density in W/m^2.

At the end of this report examples have been included to indicate the savings that are possible with a particular design strategy. These show that over 50% savings are possible when an installation has a task and building lighting approach and is controlled to provide electric lights only when they are needed. But it is considered likely that even greater savings are possible. If this order of savings could be engineered then a big step would be made in reducing the electricity used in lighting, which would contribute to reductions in carbon dioxide emissions and their impact on climate change.

Although the main thrust of this report is to encourage energy efficiency, the approach could lead to higher lighting installation costs. It is expected that a well designed installation that responds to the users' requirements and energy efficiency could well provide productivity benefits and lower operating costs. However it may be necessary to consider a realistic time span with regard to overall cost effectiveness.

Example installations of energy efficient lighting

The following theoretical examples serve to demonstrate the relative energy use when different lighting design scenarios are considered. (See figure 7.)

Example 1

An open-plan office for 12 people operates daily with a core period of 09.00 – 17.00 for 50 weeks of the year and is contained in a room 10m by 10m with a floor to ceiling height of 2.8m. The room has windows on one side that face east and therefore there is little direct sun penetration during the work period. All the windows are above a sill height of 0.85m, with a glass area of 18m^2 and are distributed evenly over the window wall. The windows are double glazed with a transmittance of 0.7. This gives an average daylight factor of 5%. Note: Average Daylight Factor is a simple way of defining the general level of daylight inside a room and it can be calculated (4 & 7).

The room surfaces reflectance values are:
Ceiling 70%, Walls 50% and Floor 20%.

The work requires a task illuminance of 500lux on the desk surface.

The room is to be lit by a regular array of ceiling recessed fluorescent lamp luminaires with white louvre attachments which provides a reasonably wide distribution of light. Each luminaire is equipped with two 1.5m, 58W, triphosphor lamps (colour 840) with a lamp light output of 5200 lumens when new. The luminaire/installation Utilization Factor is 0.67. The room is a clean environment and the lighting equipment will be regularly cleaned and a maintenance factor of 0.8 is assumed. From this the installation will require nine luminaires in three rows of three.

Office floor area = 10m x 10m = 100m^2

Office annual hours of operation = 8 (hours/day) x 5 (days/week) x 50 (weeks/year) = 2000 hours/year

Lighting load = 9 (luminaries in 3 x 3 array) x 116 (load/luminaire W) = 1044W

Average power density = 1044 / 100 = 10.44W/m^2

Total annual electricity consumption with all the lighting on for the total office operating hours =

$$\frac{1044 \times 2000}{1000} = 2088\text{kWh/year}$$

This represents 2088/3 = 696kWh/year for each row of luminaries.

Annual lighting electricity consumption density = 2088 / 100 = 20.88kWh/m^2/year

Annual cost of electricity at £0.05 per kWh = 0.05 x 2088 = £104.40 per year

The windows provide a daylight factor of 3% at approximately 3m from the windows which equates to a likely illuminance of 500lux for at least 50% of the year. Therefore if the row of luminaires nearest to the window is controlled by a light sensor to switch them off, when not required, this will reduce the total energy consumption as follows:

(696 x 0.5) + (696 x 2) = 2.5 x 696 = 1740kWh/year

This represents 83% of the total and hence a saving of 17%.

The daylighting provision also enables the second row of luminaries to be switched off for 10% of the year. Therefore the total annual electricity consumption by the three rows of luminaries =

(696 x 0.5) + (696 x 0.9) + (696) = 1670kWh/year

This represents 80% of the total and hence a saving of 20%

In this case the annual lighting electricity consumption density = 1670 / 100 = 16.7kWh/m^2/year

The savings could be increased further, by having continuous control through dimmers.

Further savings could be achieved through occupancy control but with this type of lighting to switch off individual luminaires could look odd and could lead to user dissatisfaction.

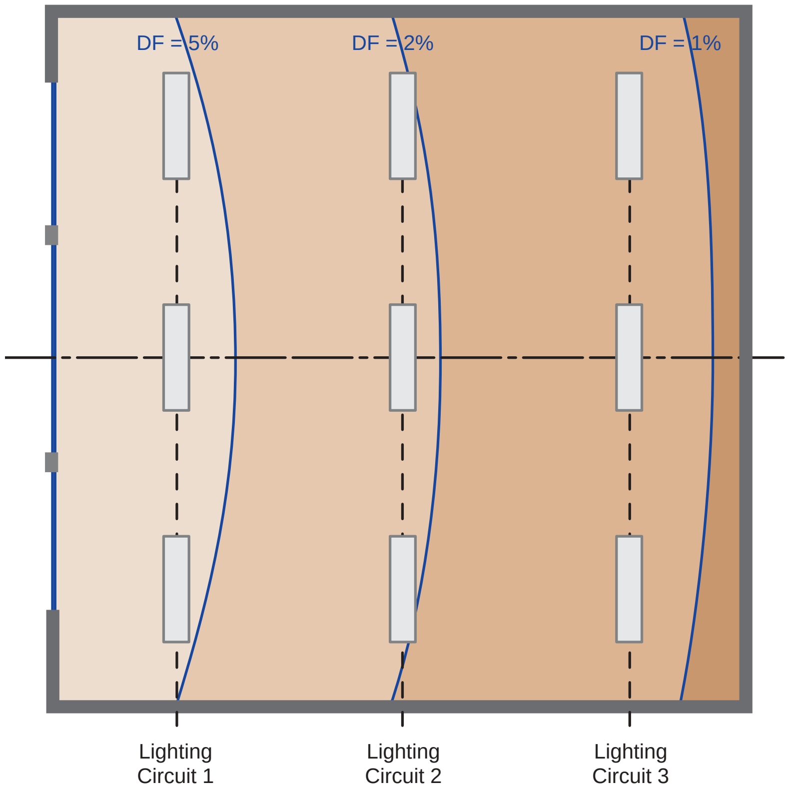


Figure 7 Office room plan for worked Examples 1 and 2 showing windows and luminaire positions. Also Daylight Factor (DF) contours.

Example 2

If we take the office as in Example 1 but this time use a ceiling lighting installation to provide an illuminance of 200lux at desk level combined with individual task lighting at each work-station to provide 500lux – a task and building lighting approach.

The following indicates the electricity consumption:

Office floor area = 100m^2

Office annual operating hours = 2000 hour/year

Number of work stations = 12

Building lighting comprises nine single 58W lamp luminaries similar to those used in Example 1 in a regular array and recessed into the ceiling.

Building lighting load = 9 (luminaries in 3 x 3 array) x 58 (load/luminaire W) = 522W

Total annual electricity consumption with all the ceiling lights on for the total operating hours =

$$\frac{522 \times 2000}{1000} = 1044\text{kWh/year}$$

Additional task lighting of 24W per person for 12 work stations = 24 x 12 = 288W

Total annual electricity consumption with all the task lights on for total operating hours =

$$\frac{288 \times 2000}{1000} = 576\text{kWh/year}$$

This represents a total annual lighting load if all lights are on for the office operating hours = 1044 + 576 = 1620kWh/year

Total annual lighting electricity consumption density = 1620 / 100 = 16.2kWh/m^2 /year

This is 78% of the annual consumption for Example 1 and hence a saving of 22%.

If the ceiling lighting installation needs to provide 200lux, with daylight linked control, this would mean that because the minimum daylight factor at the back of the room is approximately 1% the lighting is only likely to be needed for 60% of the working year.

This means that the annual building lighting electricity consumption = 1044 x 0.6 = 626.4kWh/year.

Further savings will be possible if the first and second rows of luminaries are also switched off when they are not required, but these savings have not been taken into account here.

If the task lights are switched on only to top up the background illuminance of 200lux to 500lux it is likely that they will only be required for 80% of the working year as was shown in Example 1. Hence the annual task lighting load = 576 x 0.8 = 460.8kWh/year

Total annual lighting electricity consumption = 626.4 + 460.8 = 1087.2kWh/year

Annual lighting electricity consumption density = 1087.2 / 100 = 10.9kWh /m^2/year`

This is 52% of the annual consumption for Example 1 and hence a saving of 48%.

Further savings will be achieved if task lights are switched off automatically when the workstation is not occupied.

It is estimated that for an occupancy of 75% of the time, and with task lights only being used when the combination of daylight and building lighting is less than 500lux, the use of the task lights, taking account of the daylight provision and occupancy, will be 60% of the time.

In this case the annual task lighting electricity consumption = 576 x 0.6 = 345.6kWh/year

Total annual lighting consumption = 626.4 + 345.6 = 972kWh/year

Annual lighting electricity consumption density = 972 / 100 = 9.7kWh/m^2/year

This represents 47% of electricity used for the ceiling mounted installation switched on all the time (Example 1) and hence a saving of 53%.

A number of assumptions have been made so these examples should be treated with a degree of caution; however, they indicate potential savings for different lighting design approaches.

Summary of electricity consumption for Examples 1 and 2 above.

Lighting type	Lights on at all time the office is open for 09.00 – 17.00 day		Lights on to complement daylight as required		Lights on but controlled by daylight and occupancy sensor	
Example 1 Regular array of ceiling luminaries	2088kWh /yr 20.9kWh /m^2/yr	100%	1670kWh /yr 16.7kWh /m^2/yr	80%	Occupancy controls may not be appropriate	
Example 2 Regular array of ceiling luminaries and task lights	1620kWh /yr 16.2kWh /m^2/yr	78%	1087kWh /yr 10.9kWh /m^2/yr	52%	972kWh /yr 9.7kWh /m^2/yr	47%

Note: all percentages relate back to the base installation of a regular ceiling array and switched on at all times the office is open for 09.00 – 17.00 day.

Explanation of terms

Ballast (control gear)
All discharge lamps require circuitry to start the discharge and to limit the current while the lamp is operating. These circuits consume energy so consider using low loss, high frequency and dimmable units.

Building Lighting
This describes the illumination of the building interior, which needs to complement the architecture and the application.

Building Regulations Part L
Lighting is a component of the UK Building Regulations and the current document needs to be consulted (10, 11 & 12).

CELMA Ballast Energy Classes A, B & C
CELMA, the European lighting manufacturer's association, has developed a system where the energy consumption of ballasts can be graded. The system has a set of letter grades A to C with A consuming the least energy. The energy class should be marked on the ballast casing. It is expected that regulations will determine minimum standards (5).

Colour Appearance (Correlated Colour Temperature CCT in Kelvin)
This term is used to describe the colour of the light emitted and in particular its degree of 'warmth' or 'coolness'. This is described by its CCT. Lamps that have a CCT below 3300K are classed as 'warm' and lamps that are above 5300K are classed as 'cold'.

Colour Rendering Index (CIE Ra)
The CIE general colour rendering index (Ra) is used to describe the accuracy by which a lamp can show surface colours.

If a lamp has an Ra between 90 – 100 the lamp is described as having accurate colour rendering properties, and is appropriate for accurate colour matching tasks. If a lamp has an Ra between 80 – 90 then it is appropriate for situations where accurate colour judgements are necessary e.g. shops and offices. When a lamp's Ra is below 80 then colour judgements may be impaired.

Daylight Factor and Average Daylight Factor
Because daylight illuminance is constantly changing daylight levels are described by the term Daylight Factor (DF). This is the ratio of a point daylight illuminance within a building relative to the unobstructed daylight illuminance outside. Both values exclude direct sunlight and apply to diffuse sky light under the same sky conditions and at the same time. Average Daylight Factor is a term that can be calculated and gives an indication of the likely amount of daylight within a room.

Efficacy (lumens/Watt)
The term efficacy is used to describe the energy efficiency of a lamp. It is described by the amount of light it produces in lumens with respect to the power it consumes in Watts. The term efficacy is used, rather than efficiency, because it is comparing dissimilar units.

Enhanced Capital Allowance (ECA)
The Enhanced Capital Allowance scheme enables businesses to claim 100% first year capital allowances on investments in energy saving technologies and products. Businesses are currently able to write off the whole cost of their investment against taxable profits of the period during which they make the investment. This applies to some lighting technologies and products. For details see the ECA website (13).

llluminance and Maintained Illuminance (lumens/m^2 or lux)

Illuminance is the term used to describe the level of light on a surface in lumens/square metre or lux. Maintained illuminance is the term used to describe the average illuminance on a reference surface e.g. desktop, at the time maintenance has to be carried out.

Light Output Ratio (LOR)

This is the ratio of the total light output of a luminaire, relative to the total light output of the lamp/s under reference conditions. Total LOR can be divided into downward and upward light output ratios if appropriate.

Lumen

The standard unit of light (luminous flux) used in describing light emitted by a source or received by a surface.

Luminaire (Light Fitting)

The term used to describe the apparatus that supports a lamp/s and enables it to be connected to an electrical supply. It also incorporates the light controlling elements and the lamp protection. Colloquially it is often referred to as a light fitting.

Luminous Intensity Distribution (Polar Curve)

The luminous intensity distribution, often termed the polar curve, is a graphical representation of the distribution of intensity (candela) of a luminaire and indicates the directions in which light is projected.

Power Density (W/m^2)

The power density of a lighting installation is the total power it consumes measured in Watts, and includes the lamps and any lamp ballasts, divided by the total floor area of the installation in square metres.

Room Index

This is a number that describes the size and proportions of a room for lighting design purposes.

$$\text{Room Index} = \frac{L \times W}{hm(L + W)}$$

Where L is the length of the room, W is the width of the room and hm is the height of the luminaires above the working plane.

Room Surface Reflectance

The ratio of the light reflected from a surface to the light incident on it. Except for matt surfaces this will depend on how the surface is illuminated. The value is always less than unity and is expressed either as a decimal or a percentage.

Task Lighting

This describes task illumination and it will encompass the amount of light (illuminance) and the type of light, including its colour performance, and its ability to express the task for easy and comfortable accomplishment.

Transmittance

The ratio of light (luminous flux) transmitted by a material to the light incident upon it. The value is always less than unity and is expressed either as a decimal or a percentage.

Utilisation Factor

For a particular installation, the UF is the proportion of lamp light output that reaches the working plane e.g. desktop, including both direct and reflected light.

Further reading

1. Good Practice Guide 272: Lighting for People, Energy Efficiency and Architecture, 1999, Action Energy (0800 58 57 94).

2. Good Practice Guide 300: The Installer's Guide to Lighting Design, 2002, Action Energy (0800 58 57 94).

3. Lamp Guide 2001, The Lighting Industry Federation, London.

4. Code for Lighting 2001, Society of Light and Lighting, CIBSE, London.

5. CELMA Guide on the Energy Efficiency Requirements of Ballasts for Fluorescent Lighting. (www.celma.org).

6. Good Practice Guide 160: Electric Lighting Controls – A Guide for Designers, Installers and Users, 1997, Action Energy (0800 58 57 94).

7. Good Practice Guide 245: Desktop Guide to Daylighting – for Architects, 1998, Action Energy (0800 58 57 94).

8. Lighting Guide LG10: Daylighting and Window Design, 1999, CIBSE, London.

9. Bell, James and Burt, William, Designing Buildings for Daylight, 1995, BRE, Watford.

10. Building Regulations 2000, Conservation of Fuel and Power. Approved document L1 and L2. Department for Transport, Local Government and the Regions, London (www.safety.dtlr.gov.uk/bregs/brads.htm).

11. Installer's Lighting Guide 004: Lighting Requirements for Part L of the Building Regulations England and Wales, 2001, Action Energy (0800 58 57 94).

12. Installer's Lighting Guide 005: Lighting Requirements for Meeting the Technical Standards for compliance with the Building Standards (Scotland) Regulations 1990 – sixth amendment, 2001, Action Energy (0800 58 57 94).

13. Enhanced Capital Allowance (www.eca.gov.uk).

Further information

Further information may be obtained from the following organisations:

Action Energy helpline
0800 58 57 94
www.actionenergy.org.uk

Enhanced Capital Allowance
www.eca.gov.uk

Lighting Industry Federation
207 Balham High Rd, London, SW17 7BQ
www.lif.co.uk

Society of Light and Lighting
Chartered Institution of Building Services Engineers
222 Balham High Rd, London SW12 9BS
Tel: 020 8675 5211
www.cibse.org

Tel **0800 58 57 94**

www.actionenergy.org.uk

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